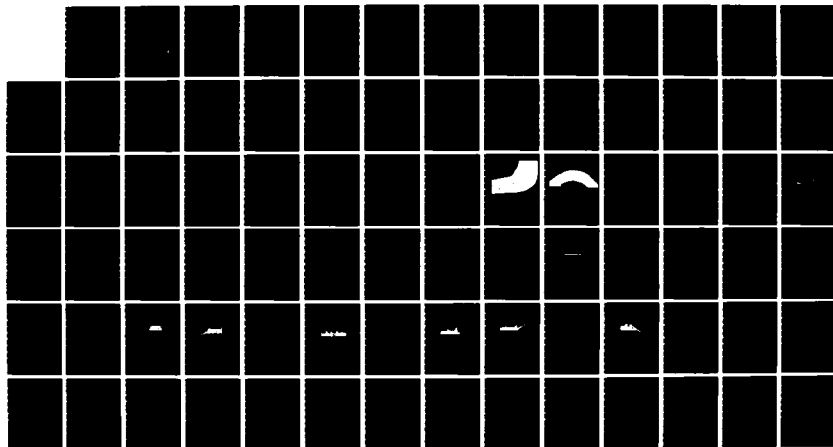


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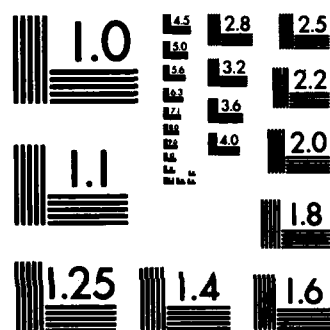
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INLAND WATERWAY DEVELOPMENT

BY

WALTER DONALD DEKIN

A REPORT PRESENTED TO THE GRADUATE  
COMMITTEE OF THE DEPARTMENT OF CIVIL  
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THE REQUIREMENTS FOR THE DEGREE OF  
MASTER OF ENGINEERING

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JUNE 1983

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In memory of my father

Ervin Dekin Jr.

Born 6 December 1922

Died 7 March 1983

N66314-72-A-3029

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It is with sincere appreciation that I thank my graduate committee chairman, Dr. Joseph A. Wattleworth and my graduate committee members Professor William W. Coons and Professor Willard G. Shafer.

The support I have received from my wife Irmgard and daughter Elizabeth has been boundless.



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## CHAPTER ONE

### INTRODUCTION

#### 1.1 BACKGROUND

The economic and reliable transportation of goods within and without the geographic boundaries of a region is critical to the development of that region. Today transportation system developers sometimes overlook civilized man's first highway, water. Water transportation, when properly planned, developed and utilized, can significantly reduce the cost of moving goods and materials. Despite the "slow and old" image that inland waterway transportation frequently brings to mind it is a highly technical undertaking which rivals any highway, railroad, or pipeline. The cost of developing inland waterways, while not inexpensive, is often far less than the cost for other modes when calculated on a cost per unit per distance unit, i.e., dollars per ton mile. Another advantage that waterways hold over other modes is that traffic can be initiated while further improvements are taking place. This should be of particular interest to developing nations, which have water resources, as a means of opening new areas to habitation and commerce "now."

In the interest of promoting the development of commercial inland waterways this paper shall present some of the basic planning, construction and utilization criteria which must be considered to determine the feasibility of such a project.



## 1.2 SCOPE OF REPORT

This report will examine the planning and development of commercial shallow-draft inland waterways. The equipment and structures necessary for their development and utilization will also be addressed. Chapter Two will outline the history of inland waterways in America to provide a prospective of their potential impact. Chapter Three will discuss some of the main social, technical, and economic problems associated with planning commercial waterways and ports. In this chapter, and throughout the rest of this report, reference will be made to the waterways of the United States when examples are deemed necessary. Chapter Four will examine the types of waterway systems, their advantages and disadvantages. Chapter Five will discuss channel design in relation to the characteristics of the vessels which are commonly utilized on American waterways. Chapter Six will discuss the types of vessels presently being used on the inland waterways of the United States. Chapter Seven will deal with the maintenance of inland waterways and will center on dredging. Chapter Eight will address the cost analysis of inland waterway development. Chapter Nine will be a summary of conclusions and recommendations.

## CHAPTER TWO

### WATERWAY HISTORY

To some, the history of water transportation is the early history of the United States.<sup>1</sup> Following the discovery of the Western Hemisphere by Columbus in 1492, explorers probed deep into the new land using rivers such as the Hudson, the St. Lawrence and the Mississippi as natural highways to the interior. Hudson, De Soto, Cartier and others found a huge, mostly uninhabited, land with abundant resources and many rivers. Settlement of this new land soon followed and by 1700 all the seaport cities of the American East Coast had been founded. While sea trade was developing, the value of America's inland waterways was not ignored. George Washington wrote in 1783, after traveling through the American hinterlands: "I could not help taking a more extensive view of the vast inland navigation of these United States and could not but be struck by the immense extent and importance of it and of the goodness of that Providence which has dealt its favors to us with so profuse a land. Would to God we may have the wisdom to improve them."<sup>2</sup> Americans were not long in showing that they possessed the wisdom of Washington. In 1787, before the adoption of the United States Constitution, a public law was passed which had and continues to have great impact on inland waterway policy in this country. This law, the Northwest Ordinance, specifically said that the rivers and waterways in the Northwest Territory were to be free and open avenues of trade and that no toll could be charged for their use.<sup>3</sup> This law

has stood the test of time and to this day no fee is imposed on vessels plying the inland waterways.

The physical characteristics of this country were significantly different in the early days as compared to now. The thick, primeval forest had yet to be cleared and passage was difficult, if not impossible. For this reason the rivers played a crucial role in opening the American frontier. Canoes, flat boats, and keelboats were assembled quickly and cheaply allowing trade and settlement to expand along the east coast and rivers such as the Hudson, Delaware, Susquehanna and others.<sup>4</sup>

Expansion westward was slowed by the rugged natural barrier of the Appalachian Mountains. Overland trails developed but the movement of goods over these trails was difficult with little true commerce taking place. More was at stake than economic development though. The success of the United States depended on the development of better communications to tie the often differing regions together.<sup>5</sup> To solve the problem, the United States took its cue from the industrial giant of the time, Great Britain. England in the mid 1700's was experiencing not only an industrial revolution but also an equally important transportation revolution. Envisaged by Francis Egerton, Duke of Bridgewater, and engineered by James Brindley, the Liverpool to Manchester canal cut the shipping cost of coal by more than 50% and spurred a canal craze.<sup>6</sup> In this country construction of canals began in the 1790's.<sup>7</sup> Federal involvement in the canal development process was considered and in 1808 the Secretary of the Treasury put forward a plan that called for the development of canals and turnpikes to link the major waterways. Politics and the War of 1812 got in the way and canal

building was left for that time to the individual states.<sup>8</sup> In 1817 lead by its foresighted Governor, Dewitt Clinton, New York State developed the Erie Canal. This canal, more than any other single entity, is credited for the development and prosperity that came not only to New York State but to the nation in the first half of the nineteenth century.<sup>9</sup> Clinton saw the canal "As a bond of union between the Atlantic and Western states,... As an organ of communication between the Hudson, the Mississippi, the St. Lawrence, the Great Lakes...and their tributary rivers," he said that "it will create the greatest inland trade ever witnessed." and, speaking of the canals effect on New York City, he said that "The city will, in the canal's effect on become the granary of the world, the emporium of commerce,...the focus of great moneyed operation,". Clinton's visions and more came to pass after the opening of the canal in 1825. New York City grew by leaps and bounds, the city and the state outdistanced all other competition in exports and commerce.<sup>10</sup> While the Erie Canal, and others spawned by its success, opened the American Midwest the steamboat soon followed to keep it open.

The steamboat allowed man, for the first time, to transport himself and his cargoes without the use of animals, or natural blessings for motivation. Animals, including man himself, had previously pulled or poled canal boats or nature had moved the vessels downstream with the flow of water or by wind power.<sup>11</sup> Now, with the advent of the steam powered boat man could move at will on the waterways. The steamboat was the precursor of all of the mechanical means of transportation we know today; trains, trucks, cars, planes, ships and pipelines.<sup>12</sup> Fulton's steamboat, its design modified by Henry Shreve

to accommodate the turbulent western rivers, opened America's mid-continent to rapid growth and development.

Water transportation enjoyed the dominant role in America until the Civil War. The war effort, on both sides, spurred the development of railroads for the movement of troops and supplies to areas inaccessible by water. Following the Civil War, railroads were king and inland water transportation seemed destined to fade away. The 1920's saw Congressional action which revitalized this important national asset and incorporated it in a modern transportation plan which includes all modes of transportation.

The legislation of the 1920's promoted improving the rivers of this country to allow their efficient utilization for transportation. Canalization was the main means of improvement. Canalization insures calm water for navigation by taming the river through the construction of control dams which eliminate or greatly reduce flooding and which create a series of slack water pools along the course of a river. Navigation around these dams is by means of locks. Other benefits of canalization can include water for hydroelectric power generation and irrigation. An important follow-on to any improvement project is maintenance. For river improvements this is particularly true. Periodic dredging and upkeep of the river training structures are required to insure the availability of the inland water system. (Training structures usually consist of some type of dike used to control the width of the low water channel.) Today over 25,000 of the 29,000 miles of navigable waterways in the United States have been improved in one way or another. Inland waterway transportation is an important part of America's multi-modal transportation network. It

provides inexpensive, efficient movement of goods for this nations commerce and employment for many thousands of its citizens.

## CHAPTER THREE

### PLANNING CONSIDERATIONS FOR COMMERCIAL WATERWAYS AND PORTS

Commercial waterways and ports are considered to be those used regularly for the movement of freight for both domestic and foreign trade. These waterways may also support passenger traffic.<sup>13</sup> The commercial waterways of the United States include the inland waterways, the Great Lakes, the coastal trade routes and the intercoastal waterways.

#### 3.1 WATERWAY PLANNING

Due to the complex task of relating the transportation function served by a water resource to the many other essential functions served by that same resource, national level jurisdiction of the development operation and maintenance of navigational improvements is beneficial.<sup>14</sup> This function, in the United States, is fulfilled, almost exclusively, by the United States Army Corps of Engineers. The planning agency must integrated the potential transportation use of a water resource with the other uses of that resource such as industrial and municipal water supply, hydroelectric power generation, waste disposal, flood control, recreation and irrigation. Some of these uses may enhance the navigation potential of a waterway while others may detract. Those seeking development of a commercial waterway system must recognize that competition for the water resource and the ultimate resource management plan will dictate the role of the waterway. It is the responsibility of the planners to provide those in decision making positions with enough accurate information to determine not only the highest and best use for a waterway but also the priority relation of the other functions.<sup>15</sup>

The complexities of water resource planning and general transportation planning have synergistically combined to obscure the role and value of waterways as commodity movers. While truck and rail freight movers often occupy the public eye, the ultimate goal of a national level transportation plan must be the development of an integrated transportation system which is capable of meeting commodity transportation needs in the most effective, economical and energy efficient manner. In many cases water transportation plays an eminent, if not preeminent, role in objective transportation plans. In the United States the ability of waterways to effectively move crude and refined petroleum, coal, grains, fertilizers, chemicals, iron ore, iron and steel products and other bulk commodities has been proven by numerous economic studies.<sup>16</sup>

The development of any type of transportation system is expensive. Therefore, the decision to build a transportation system and the selection of a particular mode as optimum must be based on sound technical and economic data. To justify building a dependable shallow-draft waterway, feasibility studies must be made which review, for each route, the amount and type of traffic anticipated, goods that would be transported, the present and potential level of regional development, the location of population centers, and the estimated construction, maintenance and operating cost. This preliminary planning phase would also require the collection and evaluation of topographic and hydrographic data, hydrologic and hydraulic data, geological information and soil characteristics. The location of all existing and proposed roads, bridges, railroads, and any other large population or industrial complex must be determined.<sup>17</sup>



Following the collection of this data, it is necessary to perform specific studies aimed at evaluating a river system's ability to accommodate commercial traffic and the type of vessels needed. Compiling channel widths and depths at various seasons, flood magnitude and frequency and information on water quality will aid in establishing capability and capacity of a river system and will lead to the type(s) of waterway selected for development. Developing an estimate of commodities to be shipped by type, season, destination, and volume will lead to determining the sizes and types of barges needed which will also play a part in determining the type(s) of waterway developed.<sup>18</sup>

The functional role of water transportation, for a given water resource, can be defined by three elements;<sup>19</sup> (1) basic freight movement capability, (2) system safety and reliability, and (3) the potential defense and emergency roles. Knowledge of these elements allow integration of a potential waterway system into a national, multi-modal, transportation network.

Defining the basic freight transportation capability of a waterway system is a highly technical planning task. Appraisal of the system's ability to meet current and future transportation needs must also take into account the full range of other water uses for the same period of time. Concurrent projections of local regional and national activities which will impact the proposed waterway will facilitate the planning activity.<sup>20</sup>

The safety and reliability of a waterway system can be defined in terms of that system's capacity vs. utilization, operational procedures and the hazardous character of the commodities commonly moved on the

waterway. Other factors which affect safety and reliability are navigation hazards intrinsic to a waterway's geometry, man-made obstructions and the general maintenance level of the waterway facilities.

A waterway's potential role in terms of defense and emergency situations will be closely related to its capacity and safety. In the United States the value of water transportation as a logistical element in defense planning is widely recognized.<sup>21</sup>

A national transportation system must be viewed as dynamic, capable of significant change to meet new demands. To that end transportation policy must be based on the objective of providing efficient, regular, and safe delivery of goods at the lowest overall cost to the consumer and to society. Integration of transportation modes to optimize the movement of goods can help meet that policy objective. A well developed national transportation policy will consider all available means of moving goods and combine those which best meet the national needs and then periodically review the needs, solutions and alternatives to insure that past policy still meets present needs.

### 3.2 PORT PLANNING

Transportation of goods by waterway is generally favored for shipment of large quantities of bulk commodities, especially between origins and destinations that are located directly on or close to the waterway. This inherent characteristic makes port planning a significant part of a waterway development plan. The basic goal of a port development plan is to maximize the utilization of an area with respect to waterborne commerce.<sup>22</sup> (This is similar to and compatible with the overall goals of national transportation planning.) Waterway port

planning, be it on a national or regional scale, should consist of four phases:<sup>23</sup> (1) definition, (2) analysis and forecast, (3) requirements and (4) formulation.

The definition phase establishes the detailed study methodology and inventories the existing marine facilities, waterway characteristics, other transportation facilities, and land uses in and around the proposed port area. Study regions are defined during this phase and the economic conditions of these areas are tabulated. Local, regional, and national policies which relate to or impact on the development of a waterway port also need to be identified during this phase.<sup>24</sup>

During the analysis and forecast phase, projections of waterborne commerce are developed which 1) take into account the impact of other transportation modes, 2) estimate cargo handling capacity requirements by commodity, and 3) examine external factors which may constrain port development.<sup>25</sup> This phase should also include a review of the areas which will contribute commercially to a port. These areas can be broken into three segments: (1) the local port area itself and the adjacent land within a nominal 25 mile radius of the port, (2) the port's natural hinterland over which it enjoys a unique advantage with respect to location, access, and services, and (3) the competitive hinterlands which can be serviced equally well by one or more other ports.<sup>26</sup>

The requirements phase translates the estimates of cargo handling requirements into terminal types, land areas, water front requirements, development cost and hinterland transportation needs. During this phase the impact of the proposed waterway port should be assessed in social and economic terms.

The formulation phase of a port planning effort should result in: a schedule for port development (including acquisition of equipment and land and development, renovation or abandonment of facilities), definition of cargo by type for each port's natural hinterland, allocation of available water and water frontage for port development, fleetings, and other non commercial uses, and a definition of responsibility for implementation.<sup>27</sup>

The "bottom line" requirements of waterway and port planning is to: (1) develop realistic estimates of potential trade, (2) know and capitalize on the strengths of a particular waterway or port and (3) have an orderly development plan that is adjusted periodically to reflect current conditions. If, after the initial studies are made and objectively evaluated, the decision is made to develop a water transportation system then the next step is to make a final determination of the type(s) of system to be developed. The various types of waterway systems, their advantages and disadvantages will be discussed in the following chapter.

## CHAPTER FOUR

### WATERWAY SYSTEMS

A waterway system can be either open river, canalized streams with locks and dams, land cut canals or any combination of these types. Each type has its advantages and disadvantages and selection of the best type(s) requires additional studies.<sup>28</sup>

#### 4.1 Open River Navigation

Open river navigation usually has the lowest initial cost of development and is favored by the towing industry in the United States because it eliminates the delay encountered in passing through locks. Open river navigation is not always practical because of the river's characteristics. Some of the problems which can be associated with this type of waterway include the need for channel training and stabilization structures, maintenance dredging, and continuous surveillance and marking of the channel which can shift due to changes in river stage and discharge. (This report assumes development of alluvial rivers.) The cost associated with the ongoing maintenance of open channel navigation can offset its low initial cost.<sup>29</sup> The feasibility of open river navigation can be determined by analyzing the following:<sup>30</sup>

1. Frequency and duration of river stages and discharges;
2. Channel width, depth and alignment, particularly during low flows;
3. Composition of river bed and banks;
4. Sediment characteristics of the river during all stages and discharge;

5. Corrective dredging required;
6. The effect on navigation of unusually wet or dry years;
7. Type and volume of traffic which could be handled with various improvement plans; and,
8. Location of disposal sites for dredge spoils.

Open river navigation can be adversely affected by constantly changing river stage and discharge, high current velocities, and limited depth during low water.<sup>31</sup>

#### 4.1.1 Stream Characteristics and Sedimentation

A natural river is a dynamic system which, due to hydraulic forces acting on its bed and banks, is constantly changing its position.<sup>32</sup> These rivers are characterized by their variations. They meander and have varying discharge and bed composition.<sup>33</sup>

Many of the problems associated with the navigational improvement of natural streams are a result of the movement or deposition of sediment in the stream channel. Sediment movement can adversely affect channel depth and alignment, it can restrict the use of navigational structures and facilities such as locks and harbors and it can affect the flood flow capacity of a stream.

The sedimentation problem must be considered in the development of navigational plans and to do so requires a knowledge of river sedimentation theory and the general characteristics of the river.<sup>34</sup>

##### 4.1.1.1 Deposition

Any stream carrying sediment can be expected to have deposition problems which will affect channel width, depth and alignment. These problems can occur in any or all of the following river conditions;<sup>35</sup>

1. Long straight reaches;

2. Long flat bends;
3. Mouths of tributaries;
4. Bifurcated channels; and,
5. Harbor entrances.

Other conditions can also cause deposition or shoaling to occur. Most shoaling problems are caused by local conditions and, therefore, require a knowledge of the problem area itself, the reach of the channel just upstream of the problem and, to some extent, the reach down stream of the problem area.<sup>36</sup> The principal consideration for the design engineer, in this situation, is to know the flow or flows during which the problem develops. This knowledge will allow supervision of the problem area and correction of any shoaling that occurs.

#### 4.1.1.2 Stage and Discharge

Changes in the stage and discharge of a river produce significant changes in the movement of sediment. Low flows, in a section of river, will develop shoaling when the flow is not capable of moving the sediment load. This shoaling will continue until velocities, slopes, and carrying capacity of the channel increase to the required levels for transport of the sediment load.<sup>37</sup>

#### 4.1.1.3 Meandering Channels

Rivers having erodible banks and beds will meander. These streams will tend to develop a sinuous course with alternating bends and some relatively straight stretches. The degree of sinuosity is dependent on many factors which include:<sup>38</sup>

1. Discharge;
2. Sediment load;
3. Bed and bank composition.

A meandering stream, unless controlled by stabilization and training works, will tend to migrate through the erosion and caving in of its banks and the subsequent deposition of this material.<sup>39</sup>

#### 4.1.1.4 Scour in Bends

During high river stages the channel in bends tends to deepen. (The stage of a river refers to the height of the river surface above some arbitrary zero point.) This deepening is caused by scouring which starts at the upper end of the bend and moves downstream as the river stage and discharge increase. As the river stage decreases, the suspended material will begin to be redeposited. This process, called shoaling, will occur in the same order that the scouring did, starting upstream and working downstream. The increase in depth, due to scouring, is considered to be a function of river stage and stage duration.<sup>40</sup>

#### 4.1.1.5 Crossing in Straight Stream Reaches

The low-water channel in long straight reaches or in long flat bends will tend to meander from one side of the river to the other. Development and maintenance of an adequate channel through these reaches is difficult. Alignment and channel depth will depend on the flow condition and can be greatly affected by the sediment carrying capacity of the upstream reach. If the upstream reach has a higher sediment carrying capacity, as is frequently the case, deposition will occur in the crossing thereby limiting the depth available for navigation.<sup>41</sup>

#### 4.1.1.6 Canal and Harbor Entrances

Entrances to canals and slack water harbors tend to promote shoaling. The entrance involves an opening in the bank line which causes a lowering of the water level and, as a result, the bottom currents and sediment move toward the entrance and are deposited. The amount of shoaling will depend on the sediment load of the stream, the location of the entrance in relation to the stream channel, the entrance size and the rate of rise and fall of the river stages.<sup>42</sup>



#### 4.1.2 Improvement of Natural Stream Channels

As discussed previously, waterways located in natural streams are subject to the streams' natural irregularities. These streams often carry heavy sediment loads, they tend to migrate and meander, they have variations in bed and bank composition and they have varying stages and discharges. Natural channels are seldom, if ever, in an equilibrium condition.<sup>43</sup> For these reasons, channel improvements are necessary to maintain natural streams in a navigatable condition. Stream improvements include channel realignment, stabilization and training structures.<sup>44</sup> The layout of the navigation project should, when practical, be based on the alignment of reaches that have been reasonably stable and that have a channel adequate for the anticipated traffic load.

##### 4.1.2.1 Channel Realignment

Channel realignment is used to reduce or eliminate the curvature of sharp bends and the tendency for shoaling. Channel realignment in conjunction with stabilization and training structures maintains channel depth and alignment for navigation. Channel realignment involves corrective dredging and cutoffs.<sup>45</sup>

##### 4.1.2.1.1 Corrective Dredging

Corrective dredging is used to realign channel and bank lines and to develop cutoffs. Dredging involves the removal from the channel bed, of alluvial deposits or erosion resistant materials.<sup>46</sup> Dredging is the most familiar method for maintaining channel configurations. Unless dredging is used in conjunction with stabilization and training structures, its results can be very temporary and it may have to be repeated after each significant rise in river stage.<sup>47</sup>

#### 4.1.2.1.2 Cutoffs

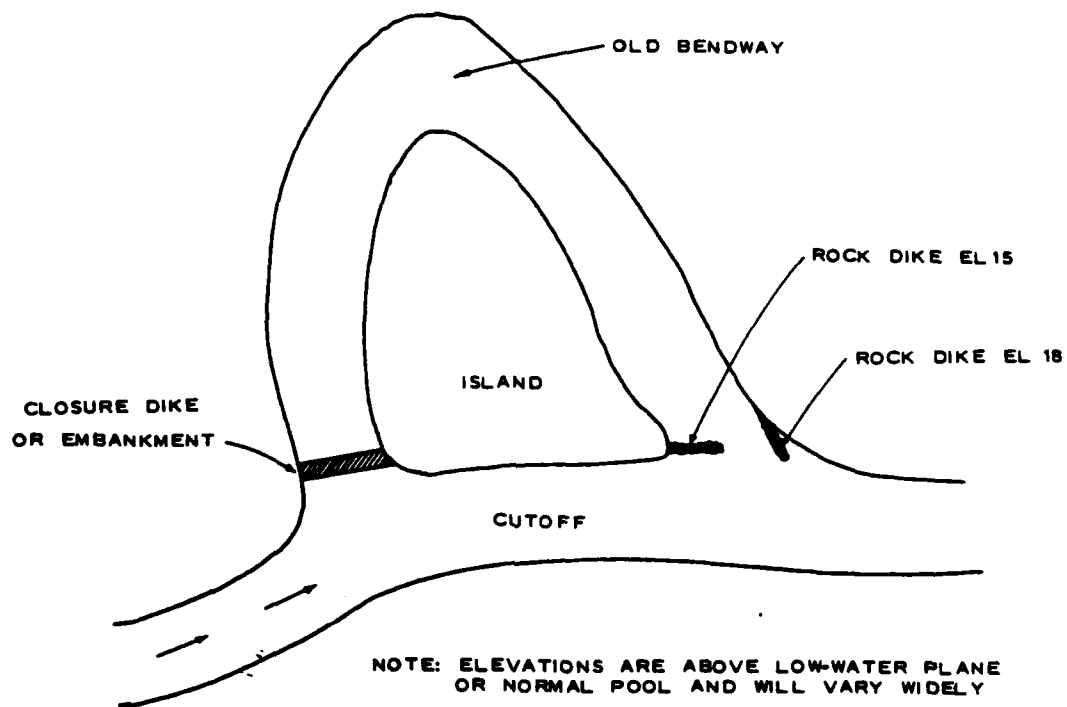
Cutoffs can be used to eliminate sharp bends and troublesome reaches from a waterway. They can also be used to reduce the navigation channel length and to increase the flood carrying capacity of the stream. Cutoffs are formed by cutting a pilot channel across the neck of one or more bends and then gradually closing the upstream end of the bend with a dike or embankment.<sup>48</sup> The old bendway, with the proper train structures can become a useful harbor. Figure 4-1 illustrates a typical cutoff and the resulting useful harbor.

#### 4.1.2.2 Stabilization

Channel stabilization involves the protection of stream or canal banks from erosion caused by currents or waves. Waves are generated by the wind or by vessel passage. The most common type of bank protection is to cover the bank at the air-water interface with some type of erosion-resistant material called a revetment. The amount of bank requiring this type of protection will be directly dependent on the current and the difference in elevation between mean high and low water for a particular stream.<sup>49</sup> Presently flexible concrete matting is used extensively in the United States as revetment material for commercially navigable waterways. Other materials which can be used range from woven fiber mats to erosion resistant plants and grasses.

#### 4.1.2.3 Training Structures

Training structures are used to develop, improve and maintain channel alignment and depth by reducing the width of the channel and stabilizing the low water channel. These structures usually consist of some type of dike constructed of timber piles, stone or piling with stone fill.<sup>50</sup>



Cutoff--old bendway used for harbor

Figure 4-1

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army, 1980, p. 7-3)

The type of structure(s) used and the arrangement of the structure(s) will depend on the problem to be solved and the stream characteristics which exist in the problem area. Figure 4-2 shows the common dike types and their placement. Dike design requires extensive experience and knowledge of the river characteristics.<sup>51</sup>

#### 4.1.2.3.1 Spur Dikes

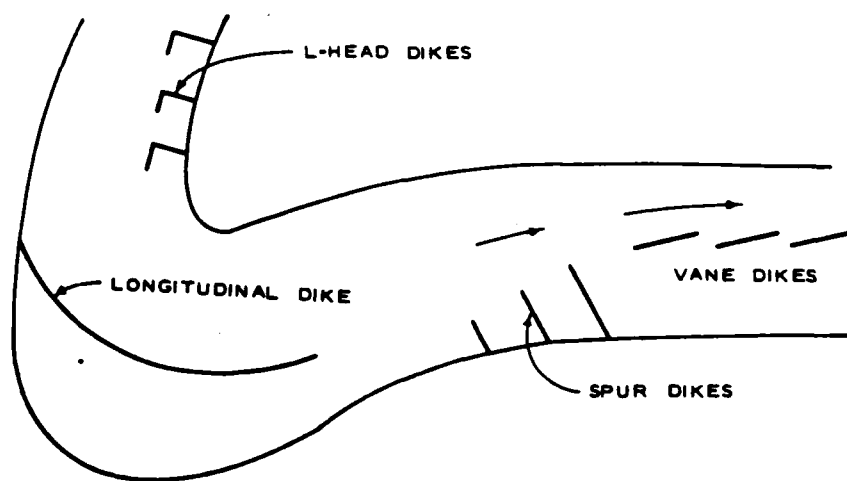
Spur dikes are the most common structure used for channel training. This dike extends from the riverbank channelward, approximately normal to the channel being developed. These dikes are generally placed in systems of two or more.<sup>52</sup>

#### 4.1.2.3.2 L-Head Dikes

L-head dikes are spur dikes with an additional section extending downstream parallel to the channel line. The L-head section can be added to the spur dike to reduce scour when the spacing between dikes is too great and they can be used to extend the spur dike system further downstream. L-head dikes tend to block the movement of sediment from the channel side to the landside of the structure. When the L-head is lower than the main dike and is topped by the stream during high stages, scouring occurs on the landward side. This can be used effectively to keep slack water harbor entrances open.<sup>53</sup>

#### 4.1.2.3.3 Longitudinal Dikes

Longitudinal dikes are continuous structures extending from the bank downstream generally parallel to the alignment of the desired channel. Longitudinal dikes are the most expensive to develop and can be the most effective when properly designed. These structures can be used to reduce the curvature of sharp bends and they provide transitions with little flow disturbance. The area landward of the longitudinal dike is often used as a site for disposal of dredge spoils.<sup>54</sup>



Types of dikes in general use

Figure 4-2

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 7-4.)

#### 4.1.2.3.4 Vane Dikes

Vane dikes were developed as a result of model studies and have proven themselves in limited applications on the Mississippi River. These dikes consist of a series of dikes placed in shallow water away from the bank at a slight angle to the desired channel. Vane dikes are economical to develop and can be used in conjunction with spur dikes or by themselves.

#### 4.2 Canalized Waterways

Canalized waterways involve the construction of dams to maintain adequate depths for navigation during periods of medium and low flows and the construction of locks to permit navigation around the dams. Locks and dams would also be required in streams which have steep gradients with velocities too high for navigation or in streams whose natural conditions make navigation impractical for other reasons. The construction of locks and dams on a stream may lessen but it will not eliminate the need for channel improvements, training structures, stabilization projects and channel maintenance. The principal disadvantages of canalized waterways is the high initial cost and the delays experienced in passing through the locks. Advantages of canalized waterways usually include lower channel velocities and wide navigation channels as compared to either open river navigation or land cut canals. Locks and dams, when provided primarily for navigation, usually consist of one or more locks, a dam for maintenance of a minimum upper pool level and other navigation and flood control accessories as required. On the inland waterways of the United States locks are usually of the low lift type with lifts varying from a few feet to more than thirty feet. The locks usually include guide and/or guard walls, an esplanade, and filling and emptying

systems. The dams presently used in the United States are predominately nonnavigable and may include gated spillways or overflow wiers.<sup>55</sup>

Locks and dams can be placed within the channel cross section of the stream with or without modification. A modification which does occur frequently is to place the locks in a cut canal separate from the dam. No matter what layout is selected, navigation problems inherent to that design should be anticipated and resolved by the use of modeling. The site selected for the lock and dam structure is one of the most important factors in the development of the waterway. Some of the factors to consider when siting are:<sup>56</sup>

1. Existing conditions in the upstream and downstream reaches;
2. Sediment movement for the various flows that might occur;
3. Effects of the structures on currents and sediment transportation; and,
4. Effects of the structures on navigational conditions.

Since accurate, adequate data is seldom, if ever, available, the use of model studies is highly recommended. These studies can help determine the adequacy of the proposed site, the best placement of the structures and these studies can highlight modifications needed to eliminate undesirable conditions.<sup>57</sup> The selection of the size and number of locks should be based on the amount and type of traffic anticipated on the waterway. The type and bulk of material which will be moved on the waterway will influence the size of barges utilized and the overall size of the flows formed. Tow size in turn dictates the size of locks required. Standard lock sizes utilized in the channelized waterways of the United States are:<sup>58</sup>

Usable Lock Dimensions, Feet

<u>Width</u>	<u>Length</u>
84	400
84	600
84	800
84	1200
110	600
110	800
110	1200

In general all new construction of locking facilities utilize the 110 feet x 1200 feet dimensions. Deviation from these standard sizes can be made at the risk of congestion and decreased efficiency of the waterway. On waterways where only small crafts or low utilization is anticipated smaller locks could be built. The construction of multiple locks should be considered if volume is excessive or if a high degree of dependability is required. Many considerations enter into the selection of lock structures and their siting. Some of the items which must be considered, but are beyond the scope of this report are:

1. Design of the upper and lower lock approach;
2. Design of guide and guardwalls;
3. Arrangement of multiple lock systems;
4. Separation of multiple locks;
5. Filling and emptying systems;
6. Lock chamber sill heights; and,
7. Types of lock construction.



#### 4.3 Land Cut Canals

Land cut canals are by far the most expensive waterway system to develop. Modern waterway development, in the United States, has shied away from this type of development because of their cost. A typical development requires locks to allow for changes in elevation and dams to provide water control and supply. A true land cut canal is not part of a river and, therefore, it does not have significant currents or sediment transportation problems. A major limiting factor of land cut canals is their size. The New York State Barge Canal, the only operating canal system in the United States with major land cut sections, is limited in these sections to vessels with a draft of 7 feet or less. The locks on the New York State Barge Canal are only 43.5 feet wide by 300 feet long. These dimensions are significantly less than those of the other inland systems in the United States that were developed around open river navigation or channelized river navigation. An advantage of land cut canals not often considered is that they can be developed anywhere sufficient water is available to fill the canal. If large rivers are not available for development but a good water supply is available, land cut canals might still be the best alternative to a transportation requirement. In general today's waterway systems are developed using all three types, open river, channelized stream and land cut canal as required to optimize the water transportation alternative.

## CHAPTER FIVE

### CHANNEL DESIGN

The type and amount of traffic that an unimproved waterway can accommodate are limited to a great extent by the available width, depth and alignment of that waterway's channel. Any attempt to improve a waterway for commercial traffic must begin by determining the characteristics of the vessels which would utilize the improved water. Required channel dimensions will vary with the vessel size and the alignment of the channel. In the United States, and elsewhere, most shallow-draft waterways utilize a combination of natural streams, channelize streams and, where necessary, land cut canals to make up their waterway. These streams and canals consist of bends and straight reaches through which the commercial traffic must pass. Required channel dimensions will also depend on whether one-way or two-way traffic is to be accommodated.<sup>59</sup> Where a low volume of traffic is forecast one-way traffic can be justified as long as passing areas are provided on straight reaches and close traffic control is maintained. Shipping companies prefer two-way unrestricted traffic for the obvious reasons of safety and increased efficiency.

#### 5.1 Channel Cross Section

When channel dimensions are discussed for waterways in the United States, their definitions are established by Section 5 of the Rivers and Harbors Act which was approved 4 March 1915. The Act reads, in part, as follows: "When width of channel is specified, it will be understood to mean the width of the bottom at project depth. Unless

otherwise expressed, channel depths will be the depth at mean low water in tidal waters...where rivers have been channelized, the channel depth referred to will be understood to signify the depth at normal pool."<sup>60</sup> Some of the basic criteria used to determine channel size are the section area ratio, the draft-depth ratio and maneuverability requirements. The section area ratio is the ratio of the channel area, to the submerged tow area. Tests conducted by the United States Army Corps of Engineers have indicated that resistance to tow movement in a restricted channel decreases rapidly as this ratio approaches 6 or 7 and then decreases less rapidly as the ratio is further increased.<sup>61</sup> Similar data developed by the United States Army Corps of Engineers shows that when the depth-draft ratio approaches 0.75 resistance to tow movement and power required to move the tow increase significantly. This is particularly true if the channel has restricted width, such as a canal or lock.<sup>62</sup>

#### 5.1.1 Channel Width

The minimum channel widths required for safe navigation in straight reaches is dependent on consideration of the following factors:

1. The size and type of equipment used on the waterway;
2. Alignment and velocity of currents;
3. Direction and intensity of the prevailing wind; and,
4. Whether one-way or two-way traffic is permitted.

The minimum channel width should be determined by defining the:

1. Tow width;
2. Clearance required between tow and channel limits; and,
3. Clearance required between tows for two-way traffic.

Operating experience on the inland waterways of the United States indicates that the minimum clearance required for safe navigation in straight reaches is 20 feet between tow and channel limits for two-way traffic, 40 feet between tow and channel limits for one-way traffic and 50 feet between tows when passing. These clearances are minimums and should be increased in channels with restricted cross-sectional area or where adverse currents could be encountered.<sup>63</sup> The United States Army Corps of Engineers have developed the following as a guide of the minimum channel widths required for tows of various widths:<sup>64</sup>

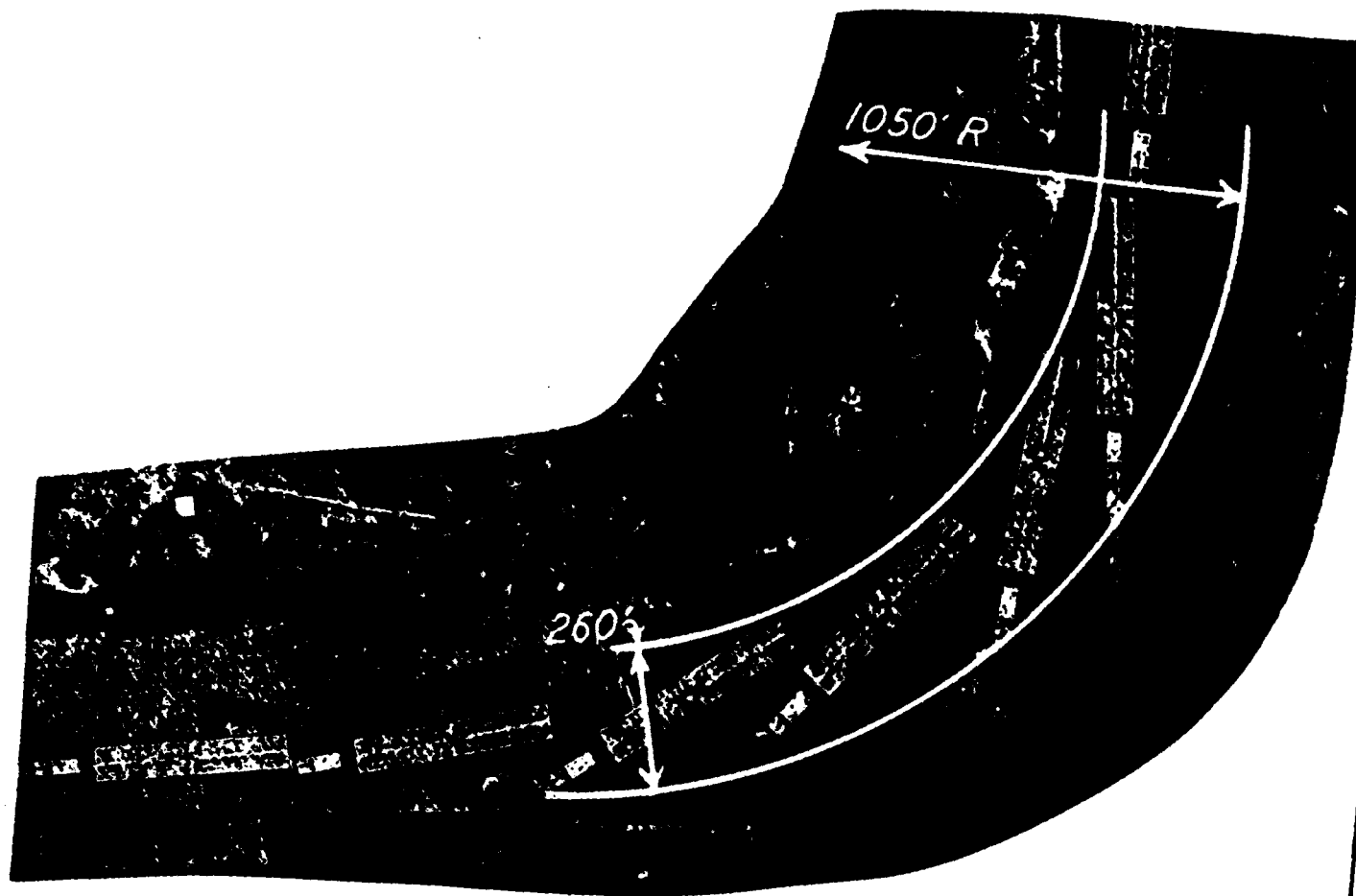
<u>Tow Width, Feet</u>	<u>Channel Width, Feet</u>	
	<u>Two-Way Traffic</u>	<u>One-Way Traffic</u>
105	300	185
70	230	150
50	190	130*

---

\* For commercial traffic channel widths of less than 130 feet are not recommended.

Recent model studies sponsored by the United States Army Corps of Engineers have focused on the additional channel widths required by tows in bends. When navigating a bend the stern of a tow is moved laterally in a direction opposite to the direction of the turn. Figures 5-1 and 5-2 demonstrate this procedure. The angle assumed and maintained by the tow to the channel alignment is called the deflection angle. This deflection angle is dependent on many factors, the most important of which are:<sup>65</sup>

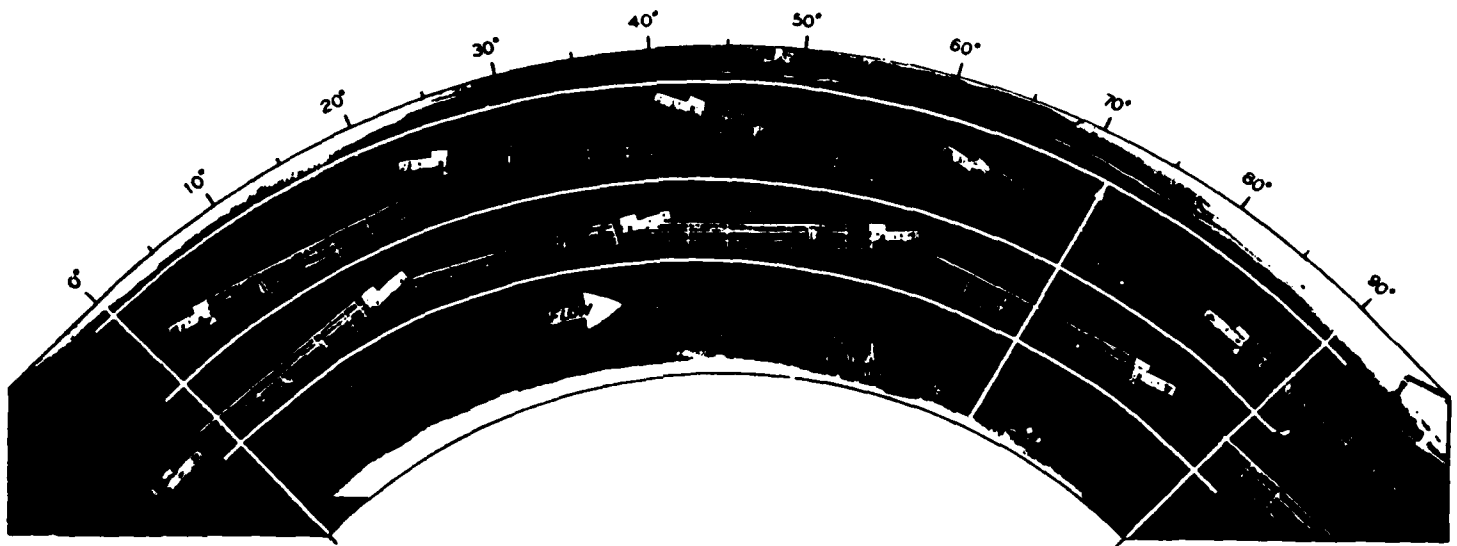
1. Radius of bend;
2. Size of tow;
3. Length of bend, in degrees (this is critical up to 90 degrees);
4. Current alignment and velocity;
5. Direction of travel (upstream or downstream);



Mosaic showing progressive location and orientation  
of a downbound 70-foot by 515-foot tow negotiating an actual  
river bend with low-velocity currents

Figure 5-1

(Source: Design and Layout of Shallow Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 4-4)



### DOWNSTREAM AND UPSTREAM NAVIGATION

Model reproducing a bend of uniform curvature and radius of 3500 feet with average velocity of 3.0 feet per second. Multiexposure photograph shows progressive movement of each of two 105-foot by 1200-foot model tows with two-way traffic

Figure 5-2

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 4-5)

6. Speed of the tow; and,
7. Alignment and position of the tow in channel when it enters the bend.

Assuming knowledge of the deflection angle of a tow as it enters a bend the United States Army Corps of Engineers model studies have resulted in two reasonably accurate, channel width equations, one for one-way traffic and one for two-way traffic. Figure 5-3 gives these formulas and defines their variables.<sup>66</sup>

#### 5.1.2 Channel Depth

Optimum channel depth is determined by evaluating many factors which include:

1. Availability of water;
2. Draft of equipment using the waterway; and,
3. Initial and maintenance dredging requirements.

Obviously the depth of channel decision is an economic decision. One that balances the cost of maintaining additional depth against the increased value of commerce made possible by that additional depth. The inland waterways of the United States can, for the most part, easily accommodate barges with drafts of 9 feet. This translates to a channel depth requirement of approximately 12 feet.

Determining Channel Widths Required in Bends. If the deflection angle assumed by a tow is known, a reasonably accurate channel width required can be determined from one of the following two equations:

a.  $CW_1 = (\sin \alpha_d \times L_1) + W_1 + 2C$

b.  $CW_2 = (\sin \alpha_u \times L_1) + W_1 + (\sin \alpha_d \times L_2) + W_2 + 2C + C_t$

where

$CW_1$  = channel width required for one-way traffic, feet

$CW_2$  = channel width required for two-way traffic, feet

$\alpha_d$  = maximum deflection angle of a downbound tow, degrees

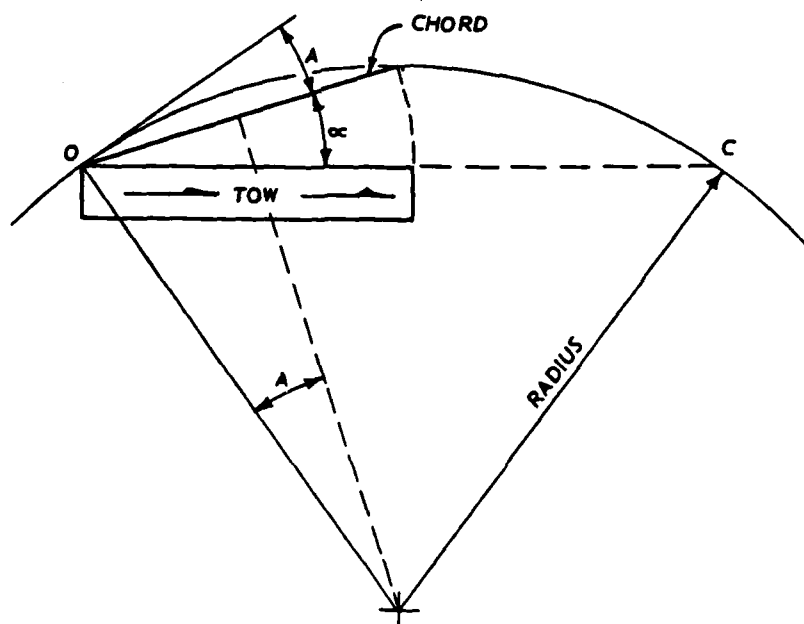
$\alpha_u$  = maximum deflection angle of an upbound tow, degrees

$L$  = length of tow, feet

$W$  = width of tow, feet

$C$  = clearance required between tow and channel limit for safe navigation, feet

$C_t$  = minimum clearance required between passing tows for safe two-way navigation, feet



Description of deflection angle  $\alpha$

LEGEND

CHORD = LENGTH OF TOW

$A$  = CHORD ANGLE

$\alpha$  = DEFLECTION ANGLE

O - C = CHORD BASED ON TOW ALIGNMENT  
MOVING THROUGH THE BENDWAY

Figure 5-3

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 4-3 thru 4-7)



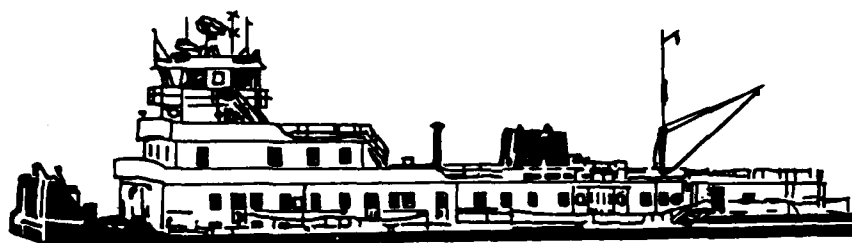
## CHAPTER SIX

### VESSEL TYPES

Inland waterway commerce in the United States is handled chiefly by barge tows made up of a towboat and one or more barges. A tow's composition can vary depending on the characteristics of the waterway, the facilities available for cargo handling, the type(s) of cargo and power and size of the tow boat.

#### 6.1 Towboats

In most cases the title "towboat" is a misnomer when applied to the boats that move the barges on America's inland waterway system. These vessels actually function as push boats.<sup>67</sup> The technique of pushing the tow provides the pilot of the tow much better control and it is a far more efficient use of the towboat's power than an astern tow.<sup>68</sup> Towboats vary in their power, size and maneuverability and therefore in their ability to handle loads. Figure 6-1 depicts the "typical" pusher towboat in use today on America's inland waterways. These towboats are functionally designed to provide a platform for its engines and crew and to transmit the power developed by its engines to the barges of its tow. The vast majority of these boats have tunnel sterns which allow the use of 9 and 10 foot screws (propellers) on these craft. The screws actually operate partially above the waterline in the funnel stern but, by design, this allows development of as much as 25% additional thrust over conventional designs. This is just one example of the efforts by naval architects to refine and optimize towboat design.<sup>69</sup>



# **TOWBOATS**

LENGTH FEET	BREADTH FEET	DRAFT FEET	HORSEPOWER
65-160	24-50	5-9	300-7000

Figure 6-1

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 3-2)

The maneuverability of the towboats is enhanced by their diesel powered twin and triple screw configuration, flanking rudders and, in some cases, bowsteerers. The multiple screws allow the towboat to develop a twisting action by reversing one screw while the other is pushing ahead. This increases the tow's responsiveness and decreases the time required to turn or swing the tow. The flanking rudders operate when the screws are backing. They enhance rudder control when backing and greatly assist in flanking maneuvers. This maneuver can be used when negotiating a bend or approaching a dock. It consists of backing the screws to reduce headway and then using the current to swing the bow of the tow in the desired direction. Bow steerers are power units located, as their title indicates, in the bow of the towboat or, in some cases, in the lead barge of the tow. They can greatly increase maneuverability by providing steering thrust from that point. Bow thrusters, while available and very beneficial, are not yet common equipment on the American inland waterways.

The pilot of the tow requires good visibility to enable him to locate channel markers, other river traffic, obstructions and navigational aids. His visibility can be affected by weather conditions (darkness, rain, fog, or snow), channel alignment, islands, structures on the banks, and his location with respect to the head of the tow.<sup>70</sup> Onboard navigational aids which enable the pilot to overcome many of these obstacles, and others, include the following:<sup>71</sup>

1. Auto pilot designed for river navigation;
2. UHF radios with up to 55 channels;
3. Teletype and telex printed information transfer;
4. Single sideband radios;

5. Depth finders;
6. Swing indicators;
7. High resolution radar;
8. True motion radar;
9. Intercoms and loudhailers; and,
10. Powerful search and flood lights.

The effect of tow configuration and pilot house elevation is illustrated by Figure 6-2. As can be seen from this figure the pilot is looking hundreds even thousands of feet ahead of his position and he must be able to control his tow within that distance.

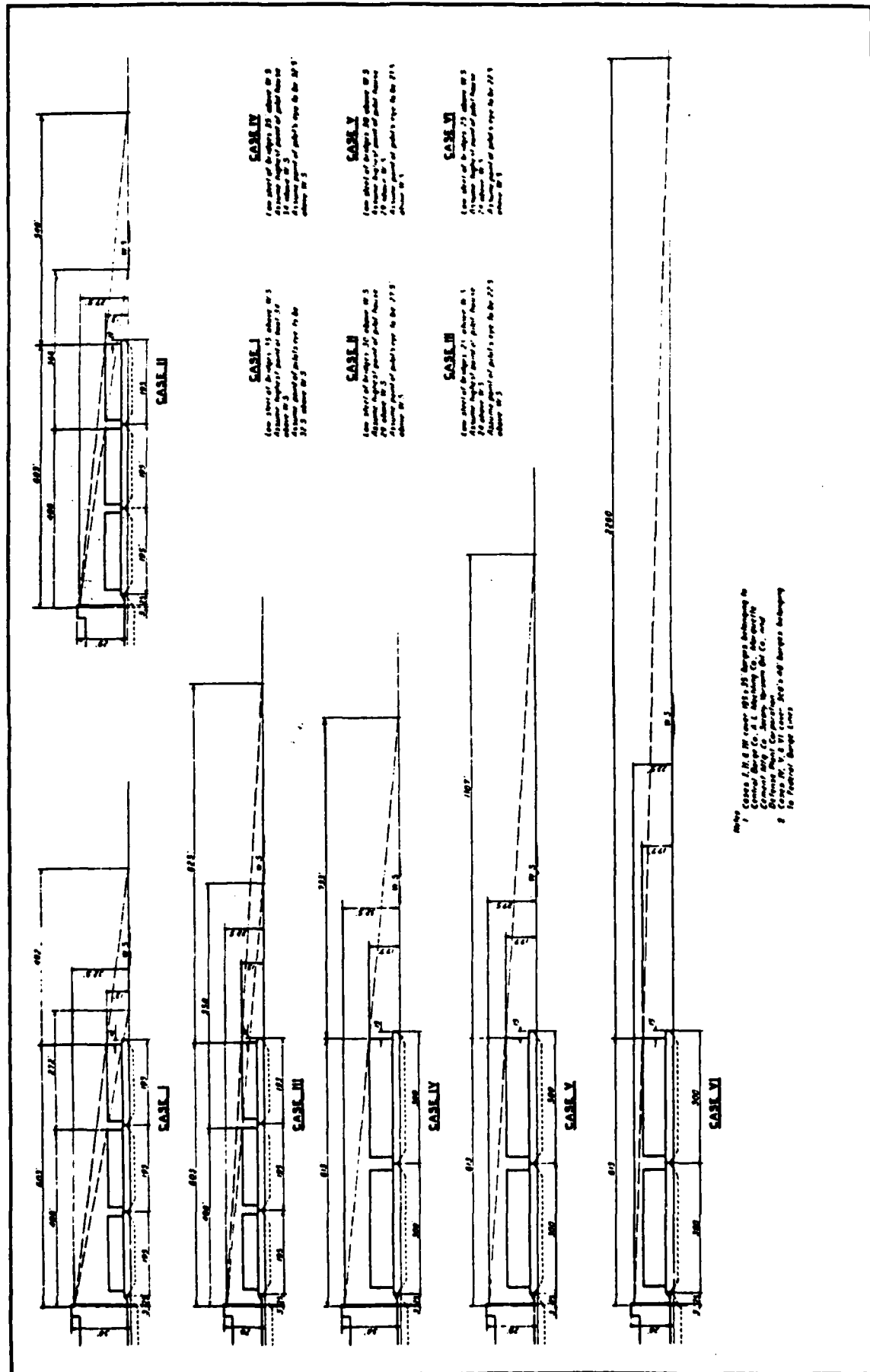
## 6.2 Barges

In conjunction with the propulsive power of a tow boat the barge becomes a highly efficient transportation mode relative to its overland competitors. Barge type and technology has developed to meet the needs of the product being transported and to be compatible with the rivers and locks, its'operational environment. The efficiency of all barge types has increased during recent decades. This increase in efficiency has been a result of improved cargo handling and fleet management techniques at the terminals and through improved barge technology. The barge improvements have taken three easily identified forms in recent times. They are:<sup>72</sup>

1. Improved barge hydrodynamics;
2. Improved barge construction; and,
3. Specialized barge design

### 6.2.1 Barge Hydrodynamics

The basic premise of barge design is to configure the barge so that it passes through the water with as little resistance and disturbance as



# Sight Analysis

Figure 6-2

(Source: Design and Layout of Shallow-Draft Waterways, Department of the Army Corps of Engineers, 1980, p. 3-5)

possible.<sup>73</sup> Reducing the resistance of a single barge is primarily accomplished by raking the bow and stern as shown in Figure 6-3. This design is the most efficient for barges that are towed singly. Tests have shown, however, that groups of double raked barges when made up in a tow cause considerable resistance and slow the speed of a tow. This type of tow is termed an unintegrated tow and is shown in Figure 6-4. The integrated tow, as shown in Figure 6-5 is the optimum multi-barge tow configuration. Made up of single rake and square-end barges this tow presents the underwater shape of a single vessel. The integrated tow, while the most efficient configuration, has one serious disadvantage. Once the tow is broken down in a port or terminal the square-end barges are very difficult to tow. For this reason the integrated tow is used only for cargos that have a single point of origin and a single point of destination such as petroleum or grain.<sup>74</sup> Since most barges see some service as individual units apart from a large tow there is another barge and tow configuration. The semi-intergrated tow, shown in Figure 6-6, is less efficient than the integrated but affords greater flexibility of the barges in port and is best suited for multi cargo multi destination situations. All barges in the semi-integrated tow are single-rake design and the tow is made up of multiples of two barges lashed square-end to square-end.<sup>75</sup>

#### 6.2.2 Barge Construction

A barge can be thought of as a floating steel box that carries cargo. Through the use of improved coatings, and fabrication techniques barge construction has been improved and barge maintenance has been reduced. Improved structural design has reduced the barge tare weight,

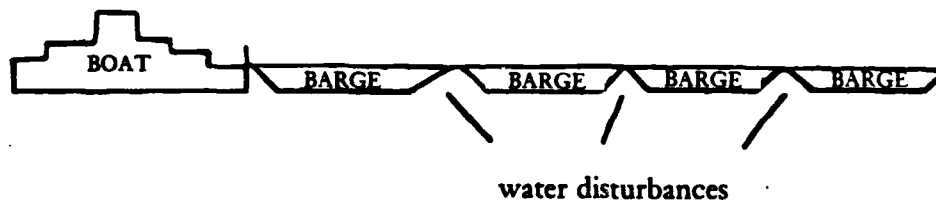
### Raked Barge



Figure 6-3

(Source: Wattenberg, Busy Waterways,  
John Day Company, 1964, p. 73)

## UNINTEGRATED TOW



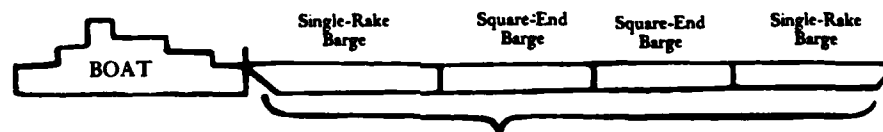
4 BARGES  
3 DISTURBANCES

Figure 6-4

(Source: Wattenburg, Busy Waterways,  
John Day Company, 1964, p. 74)



## INTEGRATED TOW



one underwater surface: no water disturbance

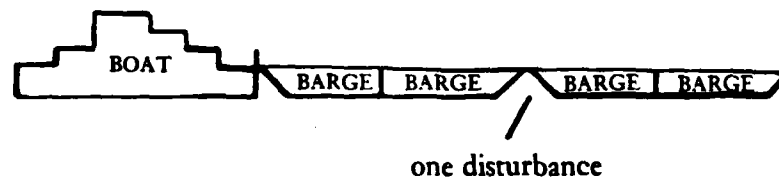
4 BARGES  
0 DISTURBANCES

Figure 6-5

(Source: Wattenberg, Busy Waterways,  
John Day Company, 1964, p. 75)

### SEMI-INTEGRATED TOW

(All barges are of single-rake design)



4 BARGES  
1 DISTURBANCE

Figure 6-6

(Source: Wattenberg, Busy Waterways,  
John Day Company, 1964, p. 77)

thus increasing the displacement available for cargo. Efficient, weight conscious design has resulted in barges which require only 375 pounds of structure per ton of capacity. This compares favorably to railroad cars which average 550 pounds per ton of capacity.<sup>76</sup> Barge maintenance has been reduced by proper preparation, priming and coating of the barge structure. The use of double hulls has further enhanced barges safety and maintainability in some instances. Aluminum barges, presently in production on a limited scale, offer advantages of lightness and low maintenance but have the disadvantages of lower strength and higher cost.<sup>77</sup>

#### 6.2.3 Specialized Barge Design

Barge design in the United States is currently directed towards comprehensive system compatibility between terminals and barges. Barges are being designed to carry particular, long-term cargo such as coal, aggregates, chemicals and petroleum. While this barge specialization is increasing there are still only four basic types of barges presently in operation on the inland waterways of the United States. These barge types differ according to the type of cargo they carry. Their functional categories are:

1. Open hopper barge;
2. Closed hopper barge;
3. Tank barge; and,
4. Deck barge.

The open hopper is the simplest and most common barge type. It is essentially an open box into which non perishable cargoes such as coal, aggregate, and pulp are loaded. This type of barge is shown in Figure 6-7.<sup>78</sup> Closed hopper barges incorporate weather tight sliding hatch covers on



#### OPEN HOPPER BARGES

TYPE	LENGTH FEET	BREADTH FEET	DRAFT FEET	CAPACITY TONS
STANDARD	175	26	9	1000
JUMBO	195	35	9	1500
SUPER JUMBO	250-290	40-52	9	2500-3000

Figure 6-7

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 3-2)

the open hopper design. These barges are used for grain, packaged goods and other products which must be protected from the weather. Figure 6-8 illustrates this type of barge.<sup>79</sup>

The tank barge carries liquids or gases and, in many ways, is the most complex. Its construction can range from single plate petroleum barges where the barge is the tank to multi wall, insulated, corrosion or high pressure resistant tanks mounted in or on a barge. Cargoes in the speciality tanks can include liquid sulfur, sulphuric acid, caustic soda, chlorine, and even wine. Figure 6-9 shows a petroleum and chemical barge.<sup>80</sup>

The deck barge has no cargo well. It is merely a floating platform for cargo that can be best transported lashed on the deck. Deck barges carry cargo ranging from air craft, heavy equipment, and bridge sections to space vehicles. An important deck barge cargo seen more and more often is loaded trailers and railroad cars. These cargoes are important because they show the integration of our commercial transportation modes into a multi-modal system.<sup>81</sup>

Coincidental with towboat and barge improvements has been a significant advancement in handling techniques at the shore terminals. Material handling methods have become highly sophisticated and automated. Future productivity improvements, on the American internal waterway system will probably come more readily at the shoreside. The waterborne equipment, barges and towboats, are very close to optimum.<sup>82</sup>



**COVERED HOPPER BARGES**

TYPE	LENGTH FEET	BREADTH FEET	DRAFT FEET	CAPACITY TONS
STANDARD	175	26	9	1000
JUMBO	195	35	9	1500

Figure 6-8

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army, 1980, p. 3-2)



**INTEGRATED CHEMICAL AND PETROLEUM BARGES**

<b>LENGTH FEET</b>	<b>BREADTH FEET</b>	<b>DRAFT FEET</b>	<b>CAPACITY TONS</b>
150-300	50-54	9	1900-3000

Figure 6-9

(Source: Design and Layout of Shallow-Draft Waterways,  
Department of the Army Corps of Engineers, 1980, p. 3-2)

## CHAPTER SEVEN

### WATERWAY MAINTENANCE

The development of a commercial inland waterway system frequently will, as already discussed, require the construction of locks and dams, training structures and the clearing of a channel. These accomplishments do not ensure a continued open and available waterway however. Since all waterways, even canals, experience flow and since flowing water is a good mover of soil, the maintenance of a waterway system will normally require dredging. The dredging cycle may be frequent or protracted but, on the United State's inland waterways, it is inevitable.

Dredging, the removal of material from underwater and disposal of it elsewhere, has been used in the United States since 1729 to construct and maintain channels, ports and harbors for commercial navigation.<sup>84</sup>

Then, as now, dredging was initiated to further commerce. Dredging, on the majority of America's inland waterways, is under the control of the United States Army Corps of Engineers. The Corps is mandated with maintaining over 25,000 miles of navigable waterways which serve 130 of America's 150 largest cities. During the year 1978, 1979 and 1980 the Corps dredged an average of 287 million cubic yards of material per year from these waterways at an average cost of approximately \$1.00 per cubic yard.<sup>85</sup> The great majority of this excavation (95%) was performed by one of several types of hydraulic (suction) dredges. The balance was done by one of several types of mechanical dredges.<sup>86</sup>



## 7.1 Hydraulic Dredge

The hydraulic dredge essentially is a centrifugal pump which draws in a mixture of water and material excavated from the channel through a suction pipe and discharges it through a pipe to a place of disposal. The suction pipe, pump, power unit and auxiliary equipment are carried on a floating barge. The means of disposal of the excavated material (spoils) characterizes the two major forms of the hydraulic dredge. These are the hydraulic pipeline dredge and the hopper dredge. Hydraulic dredges are more versatile, efficient and economical to operate than mechanical dredges since, in most cases the excavation and disposal functions are performed by one self-contained unit. Hydraulic dredges are not suited to hardrock removal nor are they well suited to use when disposal areas are small or very distant.<sup>86</sup>

### 7.1.1 Hydraulic Pipeline Dredge

The hydraulic pipeline dredge excavates material by means of a pipe attached to the suction side of a pump and transports this material to its disposal site by means of floating, submerged or shore pipeline or a combination thereof. The suction pipe is flexibly connected to various types of heads which make contact with the material to be excavated. The type of head distinguished the three major classes of pipeline dredges. These head types are the plain suction, dust pan and cutterhead.<sup>87</sup>

#### 7.1.1.1 Plain Suction Dredge

The plain suction dredge is the simplest form of pipeline dredge. It draws a mixture of water and material through a pipe lowered to the working face of the material to be removed. The mixture is then discharged through a pipeline to a disposal area. This type of dredge can dig

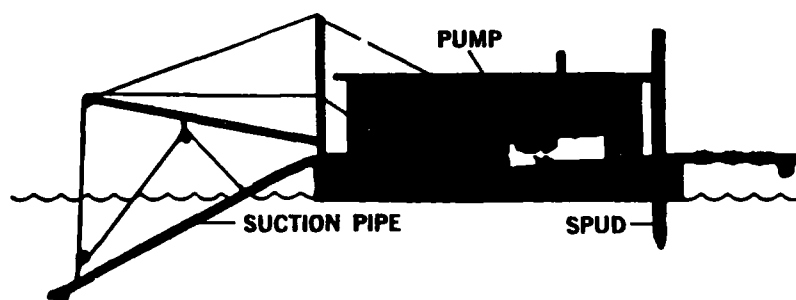
deeper than other types but it is limited to soft, free-flowing alluvial type material. The suction head is a simple structural shape attached to the end of the suction pipe. It is usually somewhat larger than the suction pipe and it may be equipped with water-jet heads to loosen and agitate the material to be excavated. They are most frequently used for the removal of silt from navigation channels. This dredge is usually a non-self-propelled floating hull, held at the work site by stern mounted spuds. These spuds are vertical posts which are attached to the barge and are forced down into the channel bottom to act as anchors.<sup>88</sup>

#### 7.1.1.2 Dust Pan Dredge

The dust pan dredge is similar to the plain suction type except that its suction head resembles a huge vacuum cleaner and it may be self-propelled. Figure 7-1 illustrates the profile of the plain suction and dust pan dredges.<sup>89</sup>

#### 7.1.1.3 Cutterhead Dredge

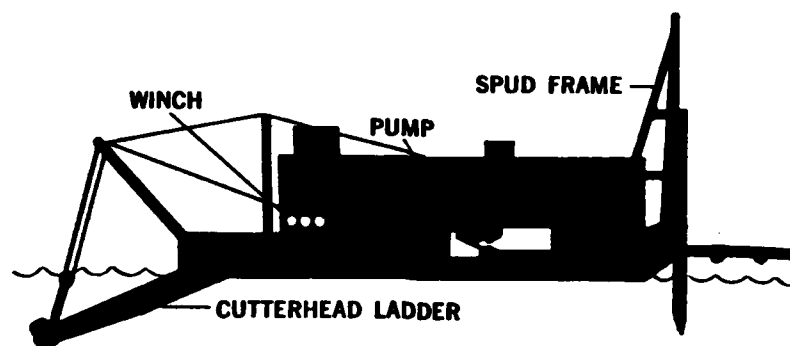
The cutterhead dredge is the most widely used pipeline dredge. The head is a rotating assembly of spiral cutting blades surrounding a suction nozzle. The cutting blades are driven by a shaft powered by a motor separate from the suction pump motor. In operation, the cutterhead rotates against the material being dredged loosening and breaking it to such an extent as to enable a suitable mixture of material and water to be drawn through the pipe and pump and to be discharged through a pipeline to a disposal area. The cutterhead dredge can remove all alluvial materials, most compacted deposits such as sand, gravel, clay and hardpan and even soft rock types such as coral, sand stone and limestone. The cutterhead is held in its working position by stern mounted spuds which can also be used to advance the dredge into the work face. Figure 7-2 profiles the cutterhead dredge.<sup>90</sup>



Plain Suction and Dustpan Dredge

Figure 7-1

(Source: Locher, Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 96)



Cutterhead Dredge

Figure 7-2

(Source: Locher: Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 96)

### 7.1.2 Hopper Dredge

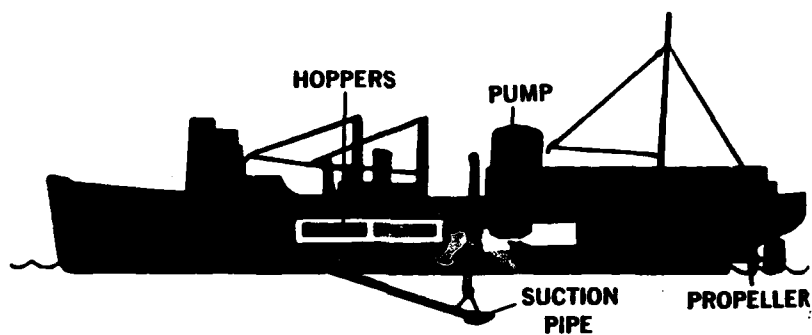
The hopper dredge, usually a sea going vessel equipped and manned for ocean navigation, functions in much the same manner as a plain suction dredge. Instead of pumping the spoils to a disposal area, the hopper dredge pumps the spoils into hoppers in its own hull. When the hoppers are loaded the dredge moves to a deep-water dumping ground and releases the material through dump doors in the bottom of the hull. The dredge then returns to the work area to repeat the cycle. Hopper dredges are used primarily in areas of heavy traffic or rough wave action which precludes the use of stationary dredges.<sup>91</sup> The profile of a hopper dredge is shown by Figure 7-3.

## 7.2 Mechanical Dredges

Mechanical dredges were the first to be developed. They consist basically of a digging bucket manipulated from a floating hull. The material excavated is then placed in scows or barges for disposal. This two-phase operation of excavation and then disposal dramatically increases the equipment required to support the operation of a mechanical dredge as compared to a hydraulic dredge. The mechanics of operation and bucket structure account for the various descriptive titles of mechanical dredges. These dredges are commonly known as clamshell, orange peel, dipper and ladder dredges.

### 7.2.1 Clamshell and Orange Peel Dredges

These dredges are essentially stiff-leg derricks or cranes on a floating platform. They operate by lowering an open grab bucket onto the material to be excavated, closing the bucket, raising it and then dumping the material by opening the bucket. The clamshell and orange peel



Hopper Dredge

Figure 7-3

(Source: Locher, Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 96)

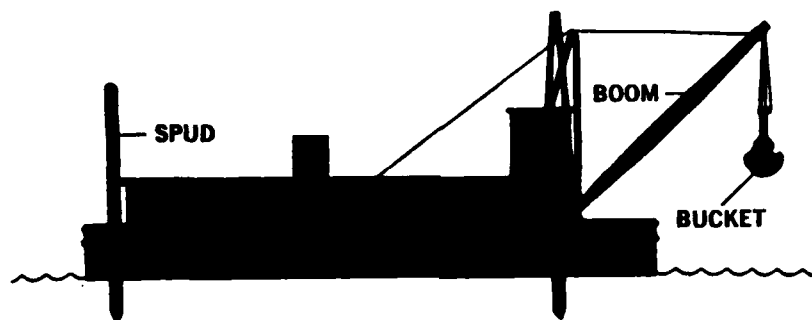
are so called because of the general shape of their bucket sections. This type of dredge is advantageous for work in confined areas near piers. They are not suited for the removal of either very soft or very hard material because the soft washes out of the bucket as it is raised and the hard resists penetration to the point that the bucket does not fill. The profile of this dredge type is shown by Figure 7-4.<sup>92</sup> This type dredge is held in position by stern mounted spuds during excavation operations.

#### 7.2.2 Dipper Dredge

A dipper dredge is basically a floating powershovel and operates a bucket on a stiff arm. The principle advantage of a dipper dredge is the strong crowding action as the dipper stick forces the bucket into the material to be excavated. Dipper dredges are best used for excavating hard compact materials. This is particularly true of rock and other hard formations after blasting operations have fractured them. Figure 7-5 profiles a dipper dredge.<sup>93</sup> This type of dredge is held in position by stern mounted spuds during dredging operations.

#### 7.2.3 Ladder Dredge

The ladder dredge consists of a series of buckets attached to an endless chain running the length of a firmly braced arm or ladder. In operation the ladder is lowered until the moving buckets contact and dig into the material to be excavated. The filled buckets ascend the ladder, propelled by the endless chain, and dump their contents into a chute at the top of the ladder. The spoils are discharged into a scow for disposal and the buckets continue down the opposite side of the ladder and the operation is repeated. Ladder dredges produce a smooth even bottom and

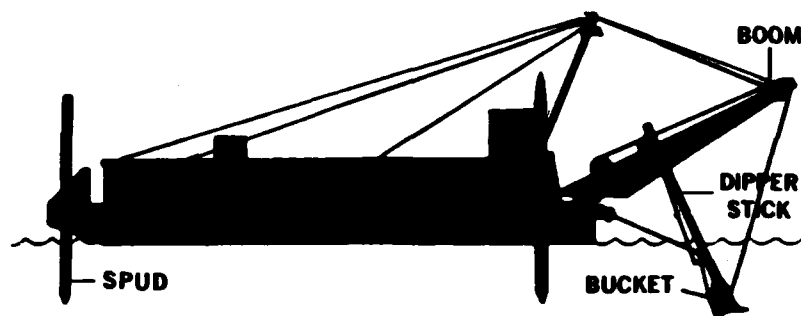


Clamshell and Orange Peel Dredge

Figure 7-4

(Source: Locher: Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 97)





Dipper Dredge

Figure 7-5

(Source: Locher, Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 97)

are more efficient than other mechanical dredges because of their continuous work cycle. Ladder dredges are used to a great extent for commercial sand and gravel production but have limited application on the inland waterway projects of the United States. This type of dredge is positioned during its operation by stern mounted spuds. Figure 7-6 profiles a ladder dredge.<sup>94</sup>

### 7.3 Support Equipment

Dredging operations can require a varying amount of support equipment. The self-propelled hopper dredge is basically self-sufficient while the non-self-propelled clamshell dredge requires numerous support barges, tugs and scows.

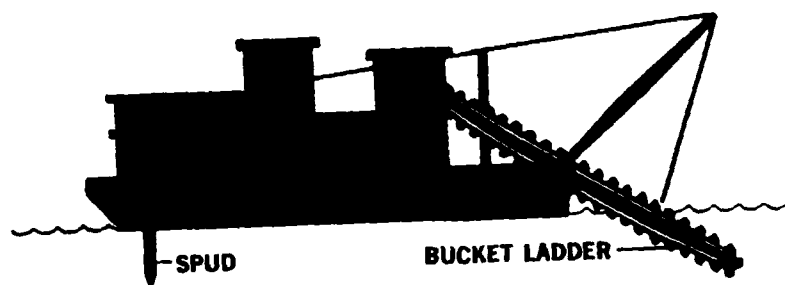
Two special types of support equipment deserve mention when discussing dredging. They are the drillboat and the dump scows.

#### 7.3.1 Drill Boat

When hard rock is encountered underwater, in an excavation area, it must be broken up so it can be removed by a dredge. In the United States, this is usually accomplished, by drilling and blasting and this in turn requires a drill boat. The drill boat is comprised of a series of rock drills secured in vertical guide frames mounted on a barge such that they can operate over the side. The barge is securely anchored, holes are drilled in the rock, charges are placed by loading tube, the barge is backed off, the rock is shot and the whole operation starts over.

#### 7.3.2 Dump Scows

The mechanical dredge ordinarily requires scows for the disposal of the excavated materials. The dump scow is generally utilized and is



Ladder Dredge

Figure 7-6

(Source: Locher, Waterways of the United States,  
The National Association of River and Harbor  
Contractors, 1961, p. 97)

a barge divided into a series of bins into which the dredged materials is deposited. There are two general types of dump scow; distinguished by their dumping method. They are the side dump and the bottom dump. The bottom dump scow is used if the depth of water in the disposal area is sufficient to allow the bottom gates to hang freely. The side dump scow is used in shallow water where the bottom dump can't operate.

## CHAPTER EIGHT

### COST ANALYSIS OF INLAND WATERWAY DEVELOPMENT

As previously discussed in this report the decision to construct an inland waterway project, or another modal project for that matter, must be based on a sound economic analysis of the project. This analysis must clearly demonstrate that, on the whole, the cost of the project, both social and economic, are outweighed by the benefits. This cost analysis is a complex procedure which requires a thorough knowledge of the project itself and all of the areas on which a project could impact. Creative development of a cost analysis procedure adequate for the review of an inland waterway project is well beyond the scope of this report, let alone an individual chapter. However, in this case, creativity is not required. The Federal Government of the United States has already prompted the creativity and 18 Code of Federal Regulation (CFR) Part 713 (18CFR 713) PROCEDURES FOR EVALUATION OF NATIONAL ECONOMIC DEVELOPMENT (NED) BENEFITS AND COSTS IN WATER RESOURCES PLANNING (LEVEL C) of 14 December 1979 is the result. The stated purpose of 18CFR 713 is to be a "...planning manual that will ensure that benefits and costs are estimated using the best current techniques and calculated accurately, consistently and...". 18CFR 713 fulfills this directive very effectively. In Subpart B - General it discusses the general criteria and definitions used in determining the NED for any waterway project. Then, in detail, it describes how to evaluate 10 different water resource development areas. Subpart I - NED Benefit Evaluation Procedures: Transportation (Inland Waterway) deals specifically

with the development or improvement of inland waterways. To demonstrate the usefulness of 18CFR 713 in the development of a cost analysis for the development of inland waterways, highlights of Subparts B and I will follow.

#### 8.1 Subpart B General

Using the concepts and definitions set forth in Subpart B one could develop a meaningful cost analysis of any project which has a determinable cost and a definable benefit. Figure 8-1 displays the index for Subpart B. The coverage of the indexed items, while brief, is concise. Of particular value are sections 713.23, 713.37 and 713.91. Section 713.23 enumerates, with definitions, the information which is required to evaluate costs and benefits at a common point in time. This information is:

1. Installation period;
2. Installation expenditures;
3. Period of analysis;
4. Benefit stream;
5. Operations, maintenance and replacement cost; and,
6. Discount rate.

To demonstrate how this information can be used to determine an optimum design the following example is presented.

#### Example Problem

Compare a concrete side port filling lock with a sheet-pile side flume filling lock and find the design with the least annual cost.

## Subpart B - General

- 713.21 Calculation of net benefits.
- 713.23 Conceptual basis.
- 713.25 Calculating net NED benefits in present value terms.
- 713.31 Risk and uncertainty - sensitivity analysis.
- 713.33 Conceptual basis
- 713.35 Planning setting.
- 713.37 Evaluation procedure: General.
- 713.39 Evaluation procedure: Problems in application.
- 713.41 Report and display procedures.
- 713.51 Project scaling using net benefit analysis.
- 713.61 Project design flood.
- 713.71 Dam failure (reserved)
- 713.81 Display of project interaction.
- 713.91 Definitions.

Figure 8-1

Given:	Concrete Lock	Sheet-Pile Lock
Installation Period (Years)	4	2
Installation Expenditures	\$60,000,000	\$25,000,000
Period of Analysis (years)	50	50
Benefit Stream (\$ per year)	6,500,000	4,000,000
Operations Maintenance and Replacement Cost (\$ per year)	50,000	500,000
Discount Rate	6%	6%

The analysis is performed for a given period of time, in this case 50 years, which includes the installation period. The benefit stream for this example would be comprised of a per lockage surcharge. The sheet pile lock, because of its design would have a slower fill time and thus its benefit stream is less. The calculation of an annual project value follows.

**Procedure:**

- Step 1 Amortize installation expenditures for the period of analysis at the discount rate
- Step 2 Calculate present worth of benefit stream and amortize this value
- Step 3 Subtract value obtained in Step 2 from value obtained in Step 1
- Step 4 Subtract the operations, maintenance and replacement cost from the result found in Step 3 this amount is the total annual project value.



	Concrete Lock	Sheet-Pile Lock
Step 1	\$3,806,400	\$1,586,000
Step 2	5,070,790	3,534,623
Step 3	1,264,390	1,948,623
Step 4	1,214,390	1,448,623

As can be seen from the above figures the sheet-pile lock is the best choice based on the given data. This simple example shows how a project can be evaluated using the information discussed in Section 713.91.

Section 713.37 discusses project evaluation and particularly those aspects which can not be characterized by a probability distribution. Sensitivity analysis is described and its applicability to project evaluation at various stages is defined.

Section 713.91 presents definitions of terms as they are used in the regulation. This is very useful since it eliminates ambiguity.

## 8.2 Subpart I - NED Benefit Evaluation Procedures: Transportation (Inland Navigation)

Subpart I does an excellent job of presenting the procedure for measuring the beneficial contributions of the inland navigation feature of a waterway project. Section 713.703 of Subpart I states the conceptual basis, "The basic economic benefit of a navigation project is the reduction in the value of resources required to transport commodities." and then it goes on to define and discuss the following categories of benefits:

1. Cost reduction benefit (same origin-destination; same mode);
2. Shift of mode benefit (same origin-destination; different mode); and,
3. New movement benefit.

Sections 713.707 thru 213.727 of Subpart I presents with explanations, the ten steps necessary to estimate navigation benefits and their interrelation

as shown in Figure 8-2. The discussion of the problems encountered in the application of the evaluation procedure which is presented in Section 713.729 of Subpart I re-emphasizes the pitfalls which can be encountered when making long term projections. The final section of Subpart I, 713.731 acknowledges that the interpretation of study results is enhanced by a clear presentation of data. Four tables are then presented in this section which should produce a clear presentation. These tables are shown as Figures 8-3 thru 8-6.

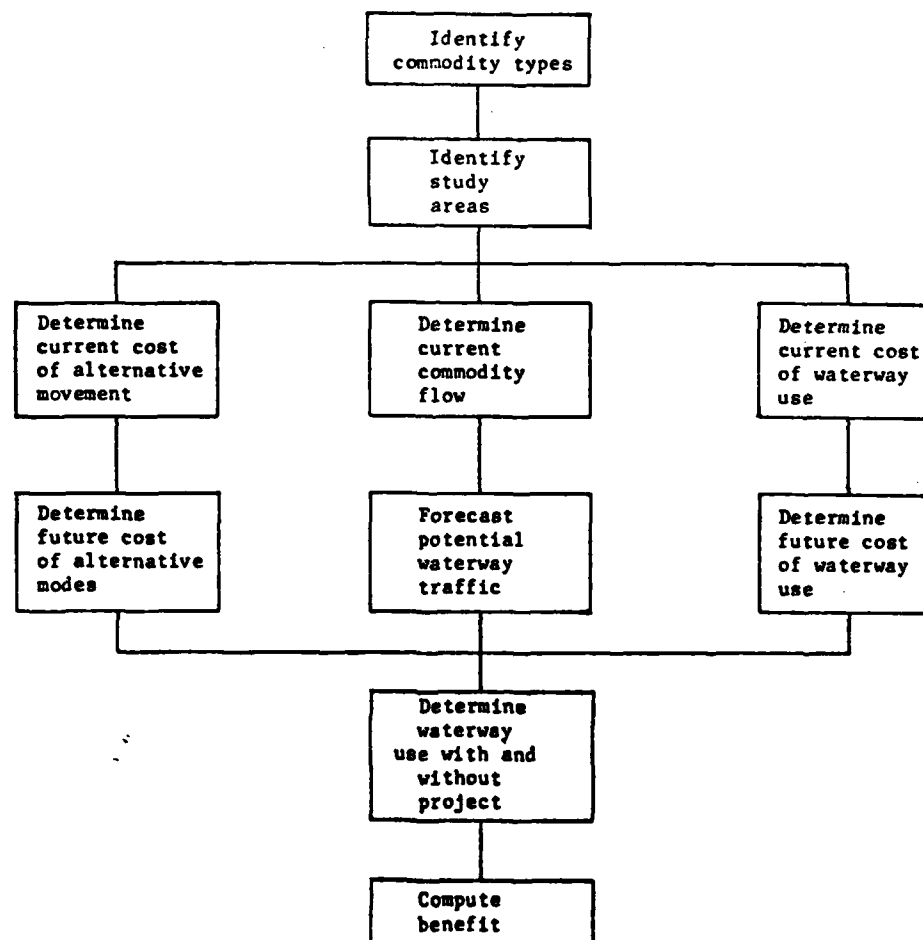


Figure 8-2

(Source: 18 Code of Federal Regulation (CFR) Part 713 (18CFR 713)  
Procedures for Evaluation of National Economic Development (NED)  
Benefits and Cost in Water Resources (level C) of 14 December 1979, p. 180)

# WATERWAY TRAFFIC AND DELAYS WITH RECOMMENDED PROJECT <sup>1</sup>

	Time period						
	Base year	Decade <sup>2</sup>					AAE <sup>3</sup>
		1	2	3	4	5	
Waterway traffic (10 <sup>6</sup> tons/year)							
(By major commodity group)							
Delays (minutes/tow):							
Study site							
Critical constraints							
Total system							
Delays (dollars/ton):							
Study site							
Critical constraints							
Total system							

<sup>1</sup> Comparable tables may be made for all detailed alternatives in the System of Accounts  
<sup>2</sup> Value for last year of decade.  
<sup>3</sup> Average annual equivalent.

Figure 8-3

(Source: 18 Code of Federal Regulation (CFR) Part 713 (18CFR 713)  
 Procedures for Evaluation of National Economic Development (NED)  
 Benefits and Cost in Water Resources (level C) of 14 December 1979, p. 187)

# WATERWAY TRAFFIC AND DELAYS, WITHOUT PROJECT CONDITION

	Time period							
	Current	Base year	Decade <sup>1</sup>					AAE <sup>2</sup>
			1	2	3	4	5	
Waterway traffic (10 <sup>6</sup> tons/year)								
(By major commodity group)								
Delays (minutes/tow):								
Study site								
Critical constraints								
Total system								
Delays (dollars/ton):								
Study site								
Critical constraints								
Total system								

<sup>1</sup> Value for last year of decade.  
<sup>2</sup> Average annual equivalent.

Figure 8-4

(Source: 18 Code of Federal Regulation (CFR) Part 713 (18CFR 713)  
 Procedures for Evaluation of National Economic Development (NED)  
 Benefits and Cost in Water Resources (Level C) of 14 December 1979, p. 187)

**SUMMARY OF ANNUALIZED  
NED BENEFITS AND COSTS FOR ALTERNATIVE  
PROJECTS**

(Applicable discount rate: —)

	Alternatives			
	1	2	3	N
Navigation benefits:				
Cost reduction benefits.....				
Shift of mode benefits.....				
Shift in origin-destination benefits.....				
New movement benefits.....				
Total navigation benefits.....				
Other purpose benefits (list).....				
Total project benefits.....				
Project costs.....				
Net benefits.....				

**Figure 8-5**

(Source: 18 Code of Federal Regulation (CFR) Part 713 (18 CFR 713)  
Procedures for Evaluation of National Economic Development (NED)  
Benefits and Cost in Water Resources (Level C) of 14 December 1979, p. 186)

**TIME PHASING OF NED BENEFITS FOR RECOMMENDED PROJECT <sup>1</sup>**

(Applicable discount rate: —)

	Base years (specify)	Time period					
		Decade <sup>2</sup>					AAE <sup>3</sup>
		1	2	3	4	5	
Navigation benefits:							
Cost reduction benefit:							
Traffic volume (10 <sup>3</sup> tons/ year).....							
Benefits.....							
Shift of mode benefit:							
Traffic volume (10 <sup>3</sup> tons/ year).....							
Benefits.....							
Shift in origin-destination benefit:							
Traffic volume (10 <sup>3</sup> tons/ year).....							
Benefits.....							
New movement benefit:							
Traffic volume (10 <sup>3</sup> tons/ year).....							
Benefits.....							
Total navigation benefits.....							
Other purpose benefits.....							
Total project benefits.....							

<sup>1</sup> Comparable tables may be made for all detailed alternatives in the System of Accounts.

<sup>2</sup> Value for last year of decade.

<sup>3</sup> Average annual equivalent.

**Figure 8-6**

(Source: 18 Code of Federal Regulation (CFR) Part 713 (18 CFR 713)  
Procedures for Evaluation of National Economic Development (NED)  
Benefits and Cost in Water Resources (Level C) of 14 December 1979, p. 186.)

## CHAPTER NINE

### CONCLUSIONS/RECOMMENDATIONS

#### 9.1 CONCLUSIONS

The impact of inland waterway development in the United States is clearly shown by the historical review presented in Chapter One. The rapid growth of this nation was directly aided by the abundance of available rivers which either could be navigated directly, improved or used to provide water for a land cut canal. Inland waterway transportation continues to play an important part in the multi-modal transportation system which operates in this country today.

Planning of any inland waterway development requires national level attention to insure that the highest and best use of the resource is realized for the public. A national transportation plan should be implemented that considers all of the available, viable transportation modes and develops an integrated system which provides the most economical means of transporting goods.

The selection of the type(s) of waterway system(s) to be developed can only be done following extensive study of the natural water resource available. Stream characteristics play an important part in determining what, if any, improvements can be made to a river system. The modifications which can be made are rather well defined but model studies should be performed before any construction takes place.

Channel design will depend on the type and volume of traffic which will utilize the waterway. Standard design parameters are available which can be readily adapted to a given situation.

The design of equipment required for the construction, maintenance and utilization of a waterway is well proven and readily available.

Inland waterway transportation, unlike other modes such as truck or train, does not require extensive construction before cargo can be moved. The shipment of goods can begin on a small scale and increase as improvements are made.

## 9.2 RECOMMENDATIONS

The companies presently involved in waterway transportation should advertise prominently in order to make the public aware of their existence and importance.

Waterway development should be addressed in our institutes of higher education not as past history, but, as a viable alternative transportation mode worthy of consideration.

National multi-modal transportation plans should be developed and implemented by the most economical modes.

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